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Multiple Targets Tracking Method Based on Finite-Set Statistics in radar system

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Abstract:

The multiple targets tracking method based on probability hypothesis density filter and its application results in radar system are given. First of all, the theory background of the PHD filtering was introduced. Secondly, the basic concepts and algorithm framework of PHD filtering are reviewed. Then the deficiencies in the engineering application are pointed out, and the Multi-targets tracking method based on PHD filter in radar system is presented. Finally, the results for engineering applications of the multiple target tracking based on PHD filtering in radar system are introduced. Results showed that the PHD filter can effectively solve the problems of Track initiation, organizing batch, and so on, under the condition of low detection probability.

Keywords:

Radar, Multiple target tracking, low detection probability, Probability hypothesis density filter, Track initiation

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1. Introduction:

After decades of research and development, the multi-target tracking technology has made great progress in theory and application. Now, it has been widely applied in many fields such as military, aerospace, environmental testing.

Typical methods include, in the traditional method of multi-object tracking: method of nearest neighbor (NN), joint probabilistic data association (JPDA), as well as the method of multiple hypothesis tracking (MHT). NN method is simple and easy to implement, but the tracking performance is poor; Standard JPDA method can only be aimed at a fixed number of target tracking; with the increasing of sensor scanning frequency and the number of measuring, MHT method is easy to appear the combination explosion phenomenon problem.

With the development of science and technology and the war environment changing, more and more sensors have been applied to the modern war. The traditional multi-sensor multi-target tracking technology has been unable to solve the problems, such as great amount of data, strong clutter interference, target dense and so on. These reasons make developing new multiple target tracking algorithm becomes a very important problem today.

The Probability hypothesis density (PHD) filtering is put forward by R. Mahler of the Lockheed Martin. It has been developing in recent years. The PHD filtering provides a new solution to solve the related problem in multiple targets tracking technology. Since PHD filter have been proposed, it has been the focus of the research object of a lot of defence agencies (such as ARO, AFOSR, MDA, AMRDEC, DARPA) in United States [1].

Since R. Mahler given the PHD filter theory, Prof. Ba-Ngu Vo and his partners have given the Monte Carlo PHD (SMC - PHD) filter [3] based on the sequence of particle approximation in University of Melbourne. Then, they have given the Gaussian Mixture PHD filter [4], i.e. the GM-PHD. As for the amount of calculation, the GM-PHD is easier to project implementation than SMC-PHD. These works make PHD filter took a key step to the practical application. After then, the PHD filter received wide attention of scholars around the world.

In today's complex war environment, the emergence of low detection probability target makes that the traditional multiple target tracking algorithm has been unable to meet the needs of the current battlefield reconnaissance and surveillance. The introduction of New multiple target tracking method to engineering application becomes more and more important. Although PHD filtering technology has become the research hotspot and focus of scholars, most of these studies focus on the PHD filtering theory, and the research of its engineering application is quite rare.

In this paper, the main objective is to introduce the engineering application results on radar systems in recent years.

Due to space limitations, this note only briefly introduced the problems and corresponding solutions that the PHD filter has encountered in engineering, and some of the engineering test results. The details of algorithm will be described in other paper. The paper is organized as follows. In the section II, the PHD filter theory is reviewed. In the section III, the advantages and deficiencies of the PHD filtering applied to engineering are analyzed, and the corresponding solutions are given. In the section IV, the experimental results are introduced, based on radar measurement data. Finally, the conclusions are given.

2. Probability Hypothesis Density Filter:

For convenience, we note

$f_{k|k-1}(\boldsymbol{X}_k \mid \boldsymbol{X}_{k-1})$ Multiple target transition probability density function ;

$g_k(\boldsymbol{Z}_k \mid \boldsymbol{X}_k)$ Multi-objective likelihood function ;

$\boldsymbol{Z}_{1:k} = \{\boldsymbol{Z}_1, \boldsymbol{Z}_2, \cdots, \boldsymbol{Z}_k\}$ The measured value set from 1 to k step ;

$p_k(\cdot \mid \boldsymbol{Z}_{1:k})$ Multi-objective posterior density ;

$p_{k|k-1}(\cdot \mid \boldsymbol{Z}_{1:k-1})$ Prediction density of multi-objective ;

γ_k Intensity of the Random set Γ_k of targets on time step k ;

$\beta_{k|k-1}(\cdot \mid \zeta)$ Intensity of the Random set of the targets came from target ζ on time step k;

$P_{S,k}(\zeta)$ Survival probability of target ζ on step k;

$P_{D,k}(\zeta)$ Probability of target ζ can be detected ;

$K_k(\cdot)$ Intensity of the Random set $\boldsymbol{K}_k$ of clutter on time step k.

Based on random finite set, the multiple target tracking problem is to get the posterior density $p_k(X_k \mid Z_{1:k})$ of the multiple target state estimate $\hat{\boldsymbol{X}}_k$ on the basis of measuring set sequence $\boldsymbol{Z}_{1:k} = \{\boldsymbol{Z}_1, \boldsymbol{Z}_2, \cdots, \boldsymbol{Z}_k\}$. The $p_k(X_k \mid Z_{1:k})$ can be obtained by the optimal Multi-target Bayesian filter in the following form of recursive iteration:

$$p_{k|k-1}(X_k | Z_{1:k-1}) = \int f_{k|k-1}(X_k | X) p_{k-1}(X | Z_{1:k-1}) \mu_s(dX) \quad (1)$$

$$p_k(X_k | Z_{1:k}) = \frac{g_k(Z_k | X_k) p_{k|k-1}(X_k | Z_{1:k-1})}{\int g_k(Z_k | X) p_{k-1}(X | Z_{1:k-1}) \mu_s(dX)}, \quad (2)$$

Where, μ_s is the reference measurement on the single target state space power set F (X) [4].

Because of the recursion expression contains a multiple integral on the single target state space power set space F (X), the corresponding amount of the calculation is very big. It's simply impossible.

Probability hypothesis density filter was proposed to solve the problem of the great amount of calculation of multi-objective Bayesian filtering [2]. PHD filter does not transfer a posteriori probability density, and only transmit the first-order statistical moment of posteriori probability density [2, 4] to approximate it. This approximate thought is mainly inspired by the constant gain Kalman filter.

The constant gain Kalman filtering is only transfer the first-order statistical moment of the single target state, i.e. the mean value.

Define: For the random finite set X on the space Xs with the probability distribution P, the first-order moment of X is a nonnegative function ν on the Xs. For any subset $S \subseteq Xs$, we have

$$\int | X \cap S | P(dX) = \int_S \nu(x) dx ,$$

Then, the function ν is called intensity corresponding P. The intensity is also called probability hypothesis density.

Under the following assumptions:
A1. The dynamic evolution and generate observations between each target are independent of each other;
A2. Clutter is obeying Poisson distribution, and Clutters are independent of the target measurements each other;
A3. Predicted multi-objective RFS is obeying Poisson distribution.

R. Mahler's PHD filter theory can be described as follows: Notes ν_k and $\nu_{k|k-1}$ respectively for multiple-target posterior density p_k and multi- target prediction density $p_{k|k-1}$. Through the Finite set statistics theory (FISST) [2] or classical probability theory, under the assumption A1 - A3, the posterior intensity v_k can be iterated on time through the PHD recursive:

$$v_{k|k-1}(x)=\int p_{S,k}(\varsigma)f_{k|k-1}(x|\varsigma)v_{k-1}(\varsigma)d\varsigma+\int\beta_{k|k-1}(x|\varsigma)v_{k-1}(\varsigma)d\varsigma+\gamma_k(x), \quad (3)$$

$$v_k(x)=[1-p_{D,k}(x)]v_{k|k-1}(x)+\sum_{z\in Z_k}\frac{p_{D,k}(x)g_k(z|x)v_{k|k-1}(x)}{K_k(z)+\int p_{D,k}(\xi)g_k(z|\xi)v_{k|k-1}(\xi)d\xi}, \quad (4)$$

It can be seen from formulas (3)-(4) that PHD recursive completely avoided the data association problem between targets and measured values. At the same time, the target intensity is only a function on the single objective state space, and then the corresponding integral is a common integral. Hence its amount of calculation is greatly reduced compared to formula (1)-(2). However, it should be pointed out that if the formulas (3)-(4) have no closed form recursive solution ’curse of dimensionality is still inevitable.

Under the condition of Gaussian and linear, B.-N. Vo and W.-K. Ma have given the closed form solution of PHD filter based on the Kalman filter "predict-revise" frame in 2006. It is named Gaussian mixture probability hypothesis density (GM-PHD) filter. GMPHD makes it possible that the PHD theory be applied in engineering. For the reason of limited space, no detail of GM-PHD is given here. One can refer to the literature [4] for more details.

3. Multi-target tracking technology in radar system based on GM-PHD filter:

3.1 Problems in application of Gaussian mixture PHD filtering

For the reason of structure simple, computational complexity low, GM-PHD filtering is becoming a hot spot of extensive research. However, there are still many problems to be solved to apply GM-PHD filtering to actual engineering. These problems include:

1) Measurement data asynchronous problem: the sensor measurement dates are all assumed time synchronization in standard GM-PHD filtering. However, the radar scanning cycle is about ten seconds in the the actual radar systems. That is to say the lag between the radar measurement points would be 10 seconds. It makes the standard GM-PHD filter cannot be applied to the actual radar system directly.
2) Priori-intensity of Clutter unknown problem: Standard GM-PHD filter requires that the Priori-intensity of Clutter is known. However, the clutter probability distribution is time-varying in engineering applications. Thus the standard GM - PHD is unable to be applied in engineering directly.
3) Problem of Target Priori-intensity of birth unknown: For target initialization, the priori-probability of target birth is must known in standard GM-PHD filtering. It

means that, In order to achieve the function of target initialization, we need to know the location where the target was born or the probably around area. For the aircraft landing site frequently, such as aircraft carrier, airport, this requirement may be feasible. In other case, for example, the low altitude penetration targets may appear anywhere in the monitoring area of radar. Hence, it is impossible to know the location the target may appear in advance.

4) The problem of track organizing batches: Though standard GM-PHD filter can estimate the number and the state of the targets in the scope of sensor, there is no data correlation function. Thus it unable to organizing batches for target track.

These problems directly affect the actual engineering application, especially for the issues like the multiple target track initializing and track organizing batches, etc. In the process of engineering design, it is the key that the GM-PHD filtering can be applied to engineering; the above problems can be solved whether or not.

The corresponding solutions of the above problems will be given in section 3.2.

3.2 Multi-target tracking in Radar system based on PHD filtering

In this section, the corresponding solutions of the problems in section 3.1 are briefly introduced. It is mainly to solve the problems the GM-PHD filtering is faced in practical radar system. For the reason of space, only the corresponding solution outlines are introduced briefly here. More details of the algorithm will be introduced in other paper.

1) For the problem of Asynchronous measurement data ：Because the radar scanning cycle is long, the time of radar system measurements are not synchronized. By dividing radar measurement area into multiple sectors, the lag between the measurement plots in same sector would be reduced to an acceptable level. Now, the point sectoring has been widely applied in the multi-target tracking processing of mechanical scan radar. Although points sectoring can effectively solve the problem of synchronization of the measured data, it will also bring new problem for the implementation of GM - PHD filtering. It is the problem of continuous tracking for across sectors target. By Gaussian ingredients joint processing in contiguous sectors, the problem is effectively solved.
2) For the problem of Clutter intensity unknown: Due to the different of radar system monitoring area, the clutter intensity distribution is also not the same. Moreover, with the time going on, the clutter intensity is changing with the time changing. To ensure the GM-PHD filtering stable operating, the nonparametric density estimation technique was adopted to estimate the clutter intensity online.
3) For the problem of target born intensity unknown: In the standard GM-PHD filtering algorithm, the target born intensity is essential for algorithm run. Considering the

accurate information of targets born location is unavailable in practical application, we adopt "Uniform target born intensity" to replace the "Gaussian mixture intensity of target born”. "Uniform target born intensity" hypothesis that target emerged with the same probability from anywhere in the monitoring area. Thus the location information target emerged is not necessary. Thereby, the GM-PHD filtering can be applied in engineering without the target born priori-intensity.

4) For the problem of track organizing batches: The essence of track organizing batches is the "data association" between the current state estimation and the history state estimation of targets. Here, the "tag technology” is "data association". Here, "Tag technology” was adopted to realize the "data association" between the current state estimation and the history state estimation of targets. Specifically, in process of GM-PHD iteration, Gaussian components inherit the label of historical track accordingly. And then the Gaussian component clip/fusion algorithm are modified respectively, the GM - PHD track organizing batches is realized.

In next section, some experimental results of GM-PHD filtering in radar system will be introduced.

4. Experimental results

In this section, we introduce the experimental results of multi-target tracking by the modified GM-PHD filtering provided in this paper with different radar’s measured data.

In the experiments, all radar monitoring area have been divided into 36 sectors evenly. The software running time is approximately 0.0002 seconds for each sector. The experimental software is programmed by C language. The CPU is Intel Core i3, and the memory capacity is 4G.

4.1 Test 1: Clutter suppression effect Validation by radar measured data

The purpose of this experiment is to validate the clutter suppression effect of the modified GM-PHD filtering provided in this paper in dense clutter area. And its performance was compared with the performance of traditional target initial algorithm, i.e. modified Logic-Based approach for track initiation. The result is shown in figure 1.

In Fig.1, the symbol "-" stands for the radar measurement plot. The symbol ＂+＂ stands for the measurements from targets identified by the modified Logic-Based approach. "Triangle" representative the measurements from targets identified by the modified GM-PHD filtering provided in this paper.

It can be seen from fig.1 that the modified Logic-Based approach can correctly identify the target measured values (" + "). But a lot of clutter was identified as the target measured values wrongly. It means that the modified Logic-Based approach does not well play the role of inhibition of clutter.
On the contrary, the GM - PHD filtering not only identifies the target measurements accurately, but also suppresses the clutter effectively.

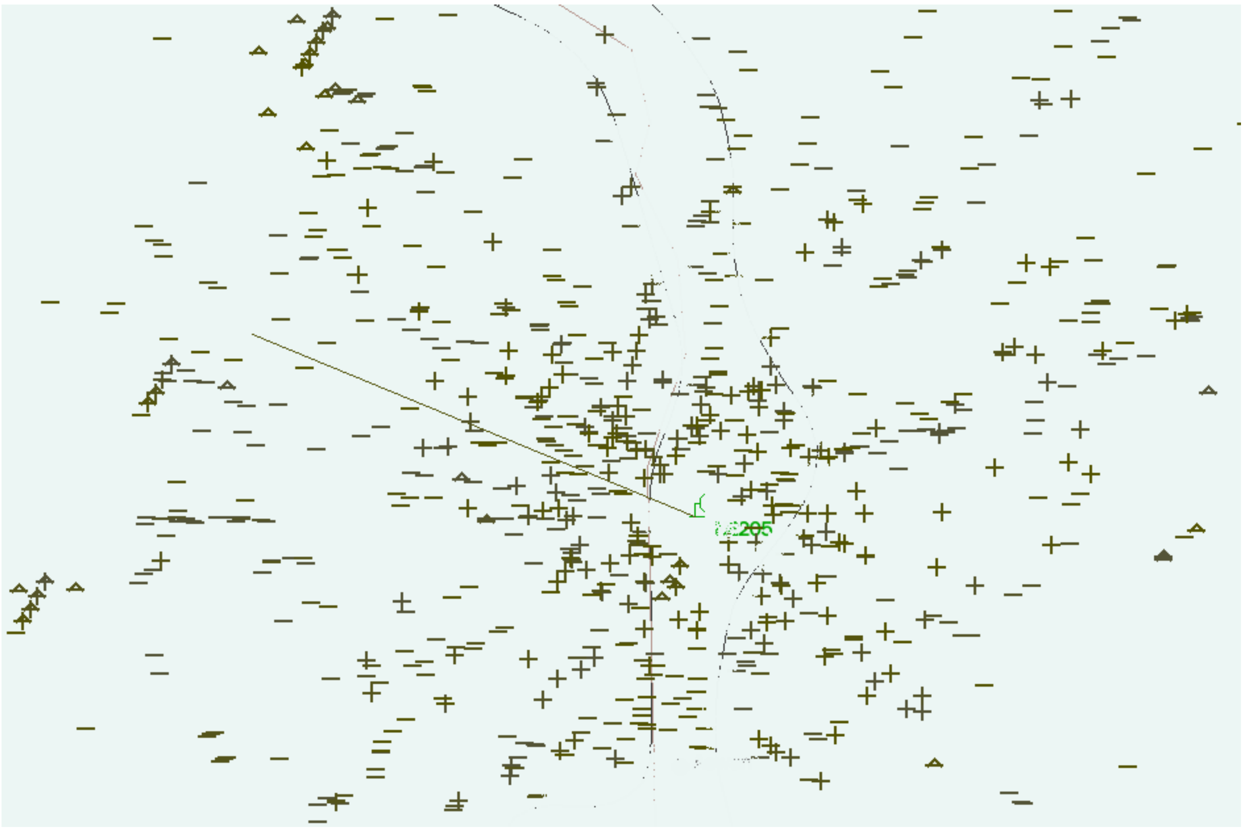

Figure (1): *Track initial result of a radar measured data*

4.2 Test 2: Track initiation and clutter suppression

The purpose of this experiment is to test the function of clutter suppressing and track initiation by using Radar measured data. The results are shown in Fig.2 and Fig.3.

The characteristic of the radar measurement point is that the clutter distribution is concentrated. It can be seen from figure 2 and figure 3 that the clutter density is dense in the area of dozens of kilometers range near the radar, and the clutter is rare in the area located away from the radar.

Similar to section 4.1, In Fig.2 and Fig.3, the symbol "-" stands for the radar measurement plot. The symbol ⎓ + ⎓ stands for the measurements from targets identified by the modified Logic-Based approach. "Triangle" representative the measurements from targets identified by the modified GM-PHD filtering provided in this paper.

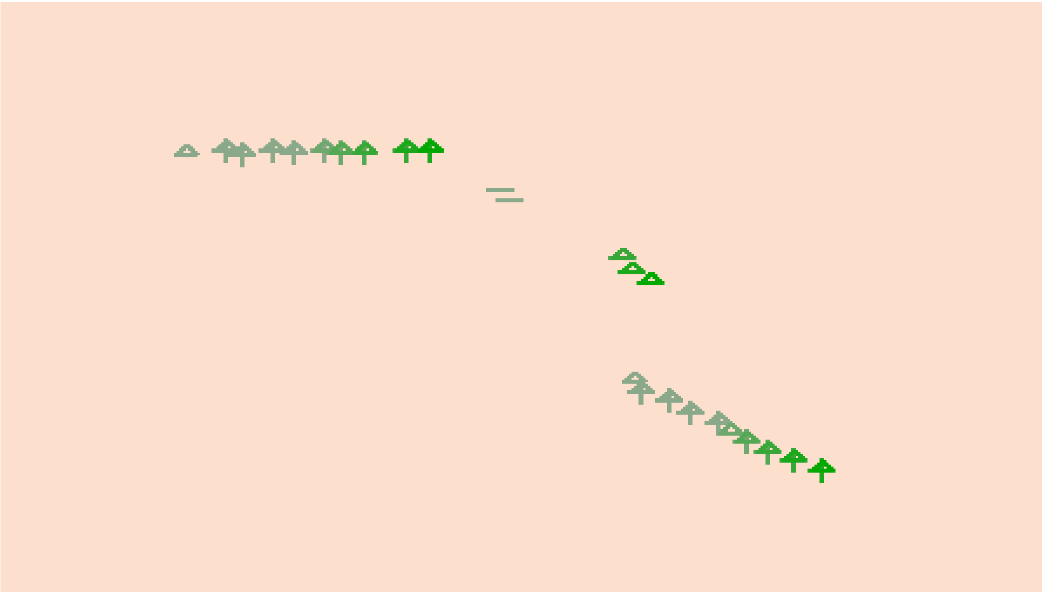

Figure (2): *Track initial result of a radar measured data*

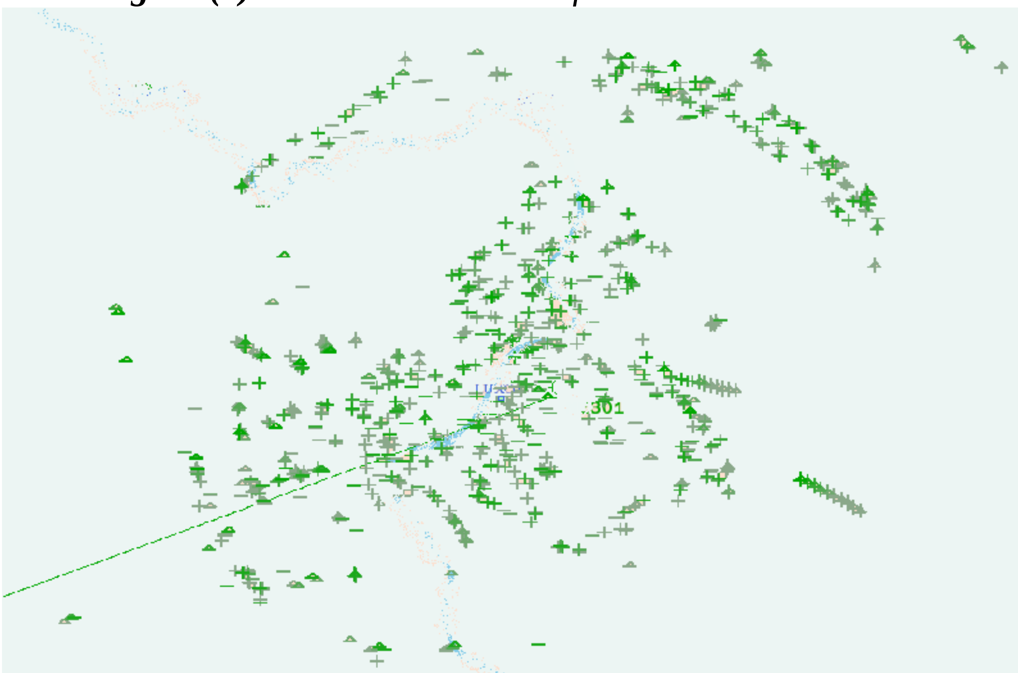

Figure (3): *Results of track initialization and clutter suppression of a radar measured data*

It can be seen from figure 2 that a total of three goals in the figure. For the middle target, because the measurement point only appeared in the first two cycles, and then lost several cycles, even if the target measured values continue to appear, the traditional target initial algorithm still cannot track initializing for this target (the "+" does not appear on the target measurement point trace). But for the modified GM-PHD filtering, when the target measurement appears again, it quickly confirmed the measurement point as the target measured value (" triangle ").

It can be seen from Fig.3 that, in the clutter dense regions of radar, two methods are enough to confirm the real target measurements. But similar to that in figure 1, a lot of clutters are identified as target measure value by the traditional modified Logic-Based approach. And the false target confirmed by the modified GM-PHD filtering is far less than those by the traditional method.

4.3 Test 3: Track initiation and batches organization for low detected probability target

The purpose of this experiment is to test the function of track initiation and batches organization of the modified GM-PHD filtering by using Radar measured data. The results are shown in Fig.4 and Fig.5.

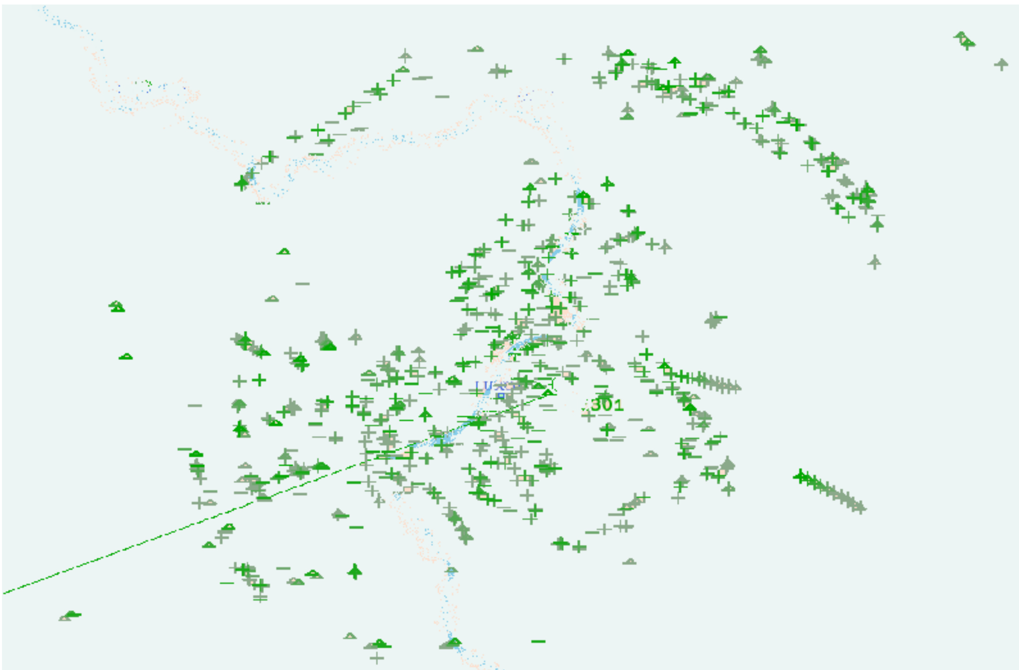

Figure (3): *Results of track initialization and clutter suppression of a radar measured data*

The characteristic of the radar measurement point is that clutter is less. But the loss phenomenon of target measured value is very serious. It means that the detected probability of target is low.

In Fig.4, Fig.5 and Fig.6, the symbol "-" stands for the radar measurement plot. The symbol "+" stands for the measurements from targets identified by the modified Logic-Based approach. The symbol "o" representative the measurements from targets identified by the modified GM-PHD filtering provided in this paper. The symbol "." represents the target track after batches organization by the modified GM-PHD filtering.

Fig.4 and Fig.5 only retain the last ten cycles of measurement points "-", the target measurement value "+" confirmed by the traditional method, and the target position "o" confirmed by the modified GM-PHD method. In order to avoid confusion, only the target track and the corresponding tracking batch number of the modified GM-PHD filtering method.

From Fig.4, we can find that, under low detected probability, when the measured value loss occurs, the modified Logic-Based approach cannot achieve the target initialization. But the modified GM-PHD filtering can do the track initialization and batches organization quickly for target (see target AA029 in Fig.4).

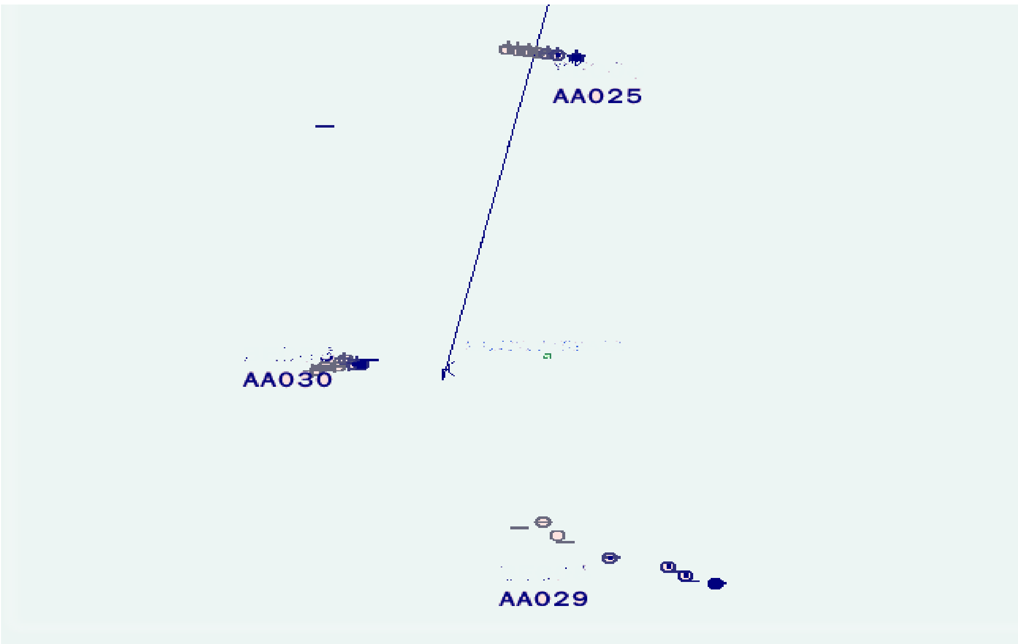

Figure (4): *Track initial result of a radar measured data*

Figure (5): *Results of track initiation and batches organization for low detected probability target*

From target AA015, AA022, AA024 in Fig.5, it can be seen that, under the condition the measurement point trace interrupt for a long time, the track come from the modified GM-PHD filtering is still continuous and stable.

Through the above test results, based on the GM-PHD filter method of multi-target tracking technology has good engineering application value, can ensure the real-time performance of algorithm is run, and in more complex engineering environment has good multiple target tracking performance.

5. Conclusion

The experiment Results based on radar measured data confirm that the modified GM-PHD filter method can be applied to the practical radar system. It can ensure the real-time performance of radar data processing. And it can suppress the clutter effectively. Under the condition of low detection probability, it can track initialize quickly and maintain of the track batch number continually and stably.

Reference :

[1] R. Mahler, Statistical Multisource Multitarget Information Fusion [M]. Norwood, MA: Artech House, 2007.

[2] R. Mahler, Multitarget Bayes filtering via first-order multitarget moments [J], IEEE Trans. Aerospace and Electronics Systems, 2003, 39(3):1152-1178.
[3] B.-N. Vo, S. Singh, and A. Doucet, Sequential Monte Carlo methods for multi-target filtering with random finite sets [J], IEEE Trans. Aerosp. Electron. Syst. 2005. 41(4):1224-1245
[4] B.-N. Vo, and W.-K. Ma, The Gaussian Mixture Probability Hypothesis Density Filter [J], IEEE Trans. on Signal Processing, 2006. 54(11): 4091-4104